XXII. Yamato 000593 (ver. 2003)

Clinopyroxenite
13.7 kg & 1.3 kg

Introduction

Yamato 000593 and 000749 are paired specimens of the first nakhlite found in Antarctica by JARE (Imae *et al*. 2002). About 60% of the surface of Y000593 is covered with a black fusion crust (figure XXII-1, not available). Another small piece (22 g), with number Y000802, was found in the same area (Kojima *et al*. 2002).

Although the nakhlites are quite similar, Mikouchi *et al.* (2003) have reported slight variations between them.

Petrography

Imae *et al*. (2002) reported that a thin section of Y000593 shows that the sample mainly consists of coarse-grained elongated augite crystals (1 mm x 0.5 mm). Accessory minerals include olivine and opaques; mesostasis includes plagioclase and magnetite. The samples appear similar to Nakhla and only lightly shocked.

As is the case with other nakhlites, Y000749 and Y000593 also have evidence of pre-terrestrial alteration (on Mars!). Some of the alteration material in Y000749 is melted near the fusion crust, "proving" its extraterrestrial origin (Treiman and Goodrich 2002).

Mineralogical Mode

	Mikouchi *et al.* (2002)
Pyroxene	85 vol. %
Olivine	10
Mesostasis	5

Mineral Chemistry

Pyroxenes: The composition of pyroxene is roughly $En_{70\text{-}50}Wo_{35}$ (figure XXII-2). The augite crystals are euhedral and elongate, up to 1.5 mm, and show polysynthetic twinning (Mikouchi *et al.* 2002).

Olivine: The composition of olivine is roughly $Fo_{20\text{-}35}$. It is sometimes surrounded by augite.

Plagioclase: Thin plagioclase laths in the mesostasis (roughly An_{30}) are crystalline and intergrown with silica.

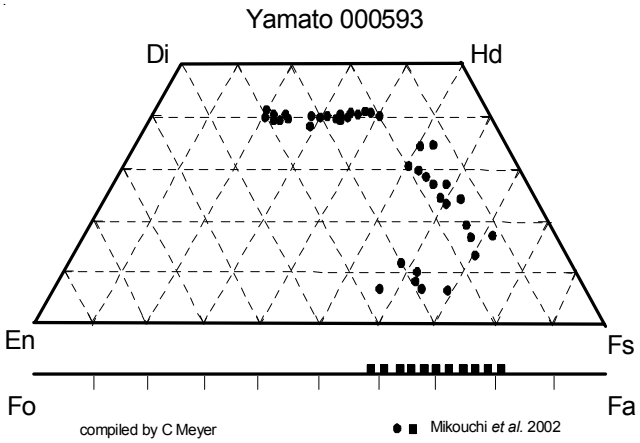

Figure XXII-2*: Pyroxene and olivine composition diagram for Yamato 000593 (data replotted from Mikouchi et al. 2002).*

"Iddingsite": Alteration is found as thin veinlets in olivine and as replacement for mesostasis in of thin section of Y000749 (Treiman and Goodrich 2002). In veinlets, the alteration material is found to be optically and chemically zoned parallel to veinlet walls *(see also section on alteration in chapter III).*

Magnetite: Magnetite is Ti-rich and up to 300 microns.

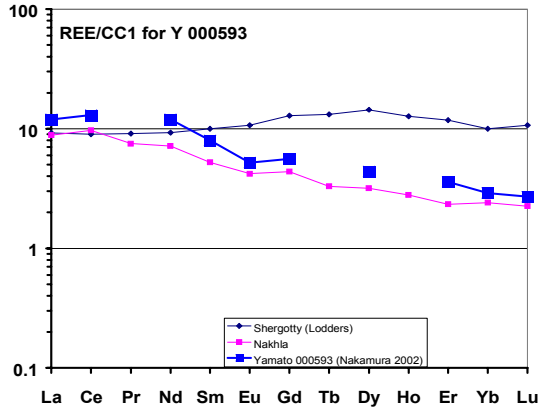

Figure XXII-3*: Normalized rare earth element diagram comparing data from Yamato 000593 with Nakhla and Shergotty (data from Nakamura et al. 2002).*

Whole-rock Composition

The composition of Y000593 has been reported by Oura *et al*. (2002), Shirai *et al*. (2002), Nakamura *et al.* (2002), Imae *et al.* (2003) and Dreibus *et al.* (2003) (table XXII-1, figure XXII-3).

Radiogenic Isotopes

Shih *et al*. (2002) and Misawa *et al.* (2003) report a Rb-Sr isochron 1.30 ± 0.03 Ga (figure XXII-4) and a Sm-Nd isochron 1.31 ± 0.03 Ga (figure XXII-5). Nakamura *et al.* (2002) reported a Rb-Sr isochron of 1.269 ± 0.240 Ga. Okazaki *et al.* (2002) determined the K-Ar age as 1.33 ± 0.18 Ga.

Misawa *et al.* (2003) also obtained an age for the alteration in Y000593 (~614 to 650 Ma), from a study of the "leachates" and "residues".

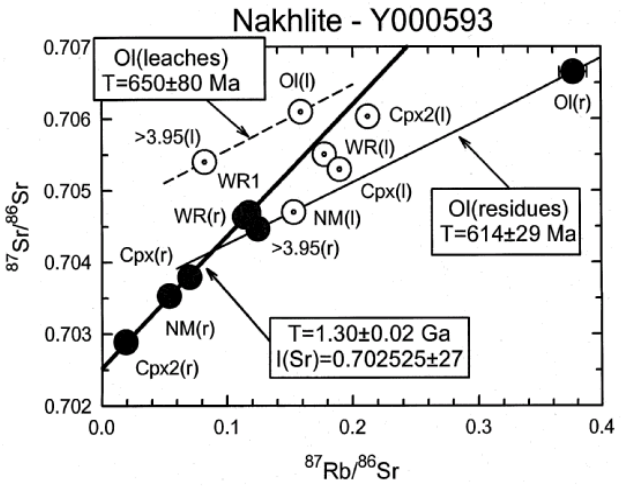

***Figure XXII-4**: Rb-Sr isochron diagram for Y000593 (data from Misawa et al. 2003, LPSC XXXIV).*

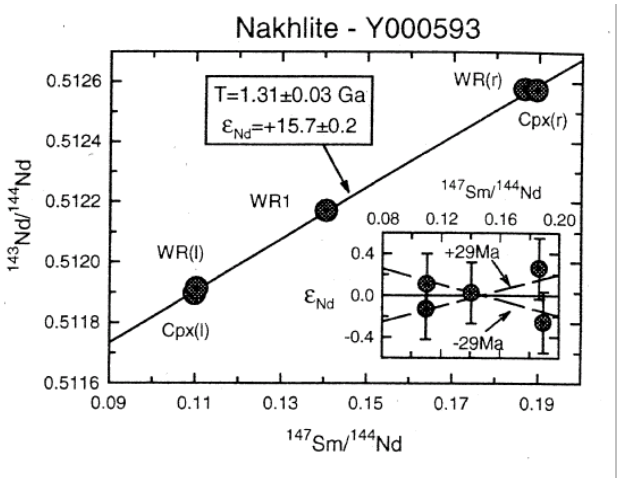

***Figure XXII-5**: Sm-Nd isochron for Y000593 (data from Shih et al. 2002).*

Cosmogenic Isotopes

Imae *et al.* (2002) determined cosmic ray exposure ages; 13.1 Ma from ^{3}He, 11.3 from ^{21}Ne, and 8.7 Ma from ^{38}Ar, which are typical of the nakhlites. Okazaki *et al.* (2002) reported 13.23, 12.16 and 7.83 Ma, respectively. The ^{81}Kr age for Y000593 measured as 11.8 ± 0.18 Ma by Okazaki *et al.* (2002), is consistent with the ^{21}Ne age of 12.16 ± 0.26 Ma.

Other Isotopes

Imae *et al.* (2002) determined Kr, Xe and Ar isotopes at various release temperatures (on sample Y000749) and found that the 1300°C fraction plotted "on a mixing line between Chassigny and iddingsite for Nakhla".

Pb isotopes were reported by Yamashita *et al.* (2002).

Other studies

Magnetic properties of Y000593 were reported by Funaki *et al*. (2002). Reflectance spectra of Y00593 were obtained by Ueda *et al.* (2002).

Processing

This large nakhlite is being studied by the Yamato Nakhlite Consortium (Kojima *et al.* 2002). The details of sample splitting and allocation distribution are described in Kojima *et al.*

Table XXII-1: Chemical Composition of Y000593.

reference	Oura 2002		Shirai 2002		Dreibus03	Dreibus03	Imae 03
weight			12 grams		593	749	
SiO2			47.57	(a)			48.35
TiO2			0.29	(a)			0.47
Al2O3			1.88	(a)			1.96
FeO			19.67	(a)	21.01	22.41	see below
MnO			0.51	(a)	0.513	0.52	0.59
CaO			14.27	(a)	13.7	13.7	14.9
MgO			10.39	(a)			11.09
Na2O			0.58	(a)	0.643	0.593	0.66
K2O			0.14	(a)			0.17
P2O5			0				0.21
sum			95.3				
Li ppm					4.6		
B	3.47	(b)	3.47	(a)			
Cl	53	(b)	52.9	(a)	101		
Sc					58.2	57.8	
V							
Cr	1790	(b)	1790	(a)			
Co	91	(b)	91	(a)	43.9	49.1	
Ni	179	(b)	179	(a)	56	72	
Cu							
Zn					89	105	
Ga					3.8	3.9	
Ge							
As							
Se							
Br					0.078	0.26	
Rb					4	4	
Sr					90	100	
Y							
Zr							
Nb							
Mo							
I ppm					0.378		
Cs ppm					0.36	0.34	
Ba					32	40	
La					2.79		
Ce					7.41		
Pr							
Nd					4.19	4.26	
Sm	1.46	(b)	1.46	(a)	1.095	1.09	
Eu					0.325	0.317	
Gd	1.17	(b)	1.17	(a)			
Tb					0.16	0.16	
Dy					1.1	0.99	
Ho					0.22	0.21	
Er							
Tm							
Yb					0.46	0.455	
Lu					0.076	0.076	
Hf					0.4	0.38	
Ta					0.115	0.105	
W ppb					300	200	
Re ppb							
Os ppb							
Ir ppb							
Au ppb					2.6	1.9	
Tl ppb							
Bi ppb							
Th ppm					0.23	0.22	
U ppm					0.055	0.058	

technique: (a) INAA and IPAA, b) PGA
note: FeO = 19.51, Fe2O3 =2.04